RECURRENT HOLOCENE PALEOSEISMICITY AND ASSOCIATED LAND / SEA LEVEL CHANGES IN THE GREATER ANCHORAGE AREA - Annual Report November 2004

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Investigations undertaken

Determining the potential for future earthquakes in the U.S. and reducing losses requires knowledge on how often earthquakes have occurred in the past and at what magnitude. This project applies new temporal and vertical techniques to better understand long records of Holocene palaeoseismicity and associated land/sea-level changes in the greater Anchorage area from sedimentary sequences at three sites: Ocean view (Anchorage), Girdwood and Kenai. Evaluating future earthquake risk in the region affected by the great Alaska earthquake of AD 1964 requires knowing how frequently events of this magnitude occur, at what intervals and how the patterns of land movements vary in different events. This project aims to: improve understanding of Holocene ground displacements in the greater Anchorage area; improve the vertical, spatial and temporal resolution of geological estimates of elevation change from Holocene earthquakes in Alaska (with the quantitative methods applicable to Cascadia); determine the recurrence intervals of great earthquakes in the greater Anchorage area; quantify the methods of using microfossil and stratigraphic data in reconstructing Holocene land movements during repeated earthquake cycles; and finally assess the potential of pre-seismic relative sea-level rise as an early warning of an imminent earthquake by identifying its magnitude during multiple Holocene earthquakes at different sites.

Fieldwork in July 2003 collected stratigraphic data from three tidal marshes in, and around the greater Anchorage area: Girdwood, Ocean View (Anchorage) and Kenai (Figure 1.1). We combine the results of this fieldwork with data collected and analysed by Hamilton (2003), Zong *et al*. (2003) and Shennan *et al*. (2003). To address the research questions outlined above we undertook:

1. Collection of sediment cores or exposed sections to cover two or more late Holocene events at Ocean View (Anchorage), Girdwood and Kenai.
2. Fieldwork at Ocean View (Anchorage), Girdwood and Kenai to assess evidence of any tsunami deposits associated with late Holocene earthquakes within the greater Anchorage area.
3. Microfossil analysis of samples from the three sites.
4. Application of new vertical techniques (quantitative diatom transfer functions) to improve elevation accuracy and resolution of geological estimates of co-seismic and inter-seismic land-level changes from great Holocene earthquakes in Alaska.
5. Analyse evidence for pre-seismic relative sea-level rise.
6. Analyse new radiocarbon dated samples and compare with previously dated material to investigate the coastal extent and recurrence intervals of plate-boundary ruptures.

Summary of results

[Additional details appear in the Final Report, submitted to USGS/NEHRP, November 2004 and Hamilton & Shennan (2005, in press) and Hamilton *et al*. (2005, in press) – details below]

Chronology of great earthquakes

Comparison of AMS radiocarbon ages on paired samples of bulk peat and *in situ* plant macrofossils show a significant older age for the bulk peat sample in virtually all cases (Figure 1). Despite the fact that the ages for the peat layers described in this report may fit with some co-seismic movements reported for Cook Inlet (Combellick, 1994), Copper River Delta and Middleton Island (Plafker *et al*., 1992), it is very clear that no reliable chronology can be based on bulk peat dates (c.f. Bartsch-Winkler and Schmoll, 1992; Combellick, 1994), whether using AMS or conventional radiocarbon methods. A new chronology (Figure 2) uses only AMS radiocarbon ages from *in situ* plant macrofossils and two conventional ages on *in situ* tree roots submerged after the penultimate earthquake at Girdwood (Combellick, 1993). We regard these ages as reliable.

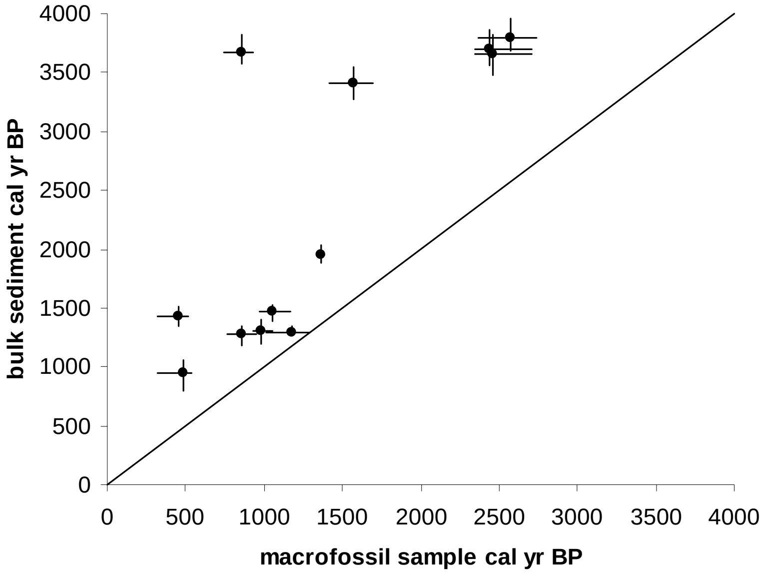


Figure 1: Comparison of AMS radiocarbon ages of paired samples from bulk peat and in situ macrofossils extracted from the peat (data from Hamilton, 2003 and this report), plotted as median calibrated ages with 2σ error range.

Stratigraphy and diatom evidence provide clear evidence of six great earthquakes during the last ~3300 years at intervals ranging from ~400 to ~900 years (Figure 2). Below we summarise subsidence at Girdwood, Ocean View and Kenai associated with each great earthquake and consider the possibility of further great earthquakes within the record.

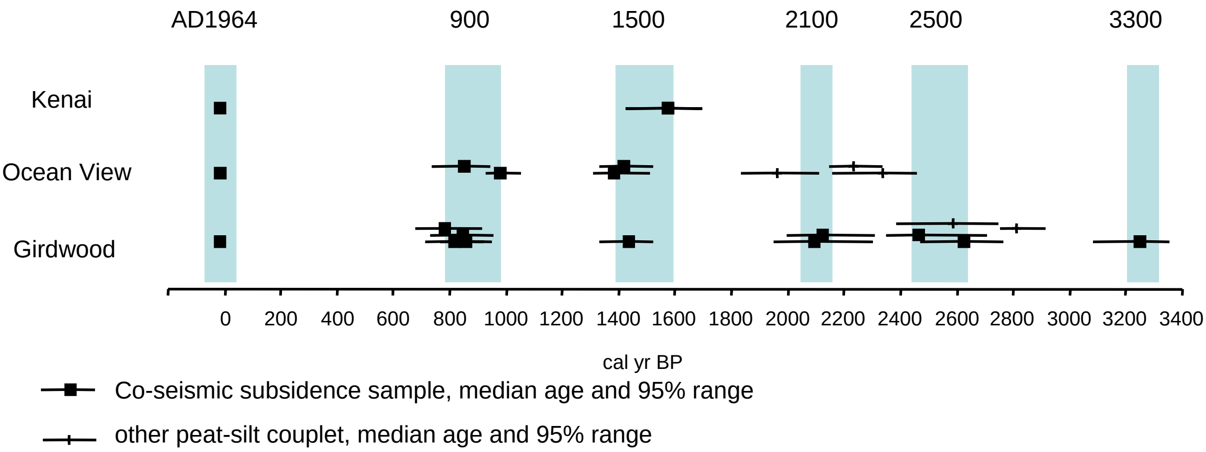


Figure 2: Ages of earthquakes recorded at three sites around the Cook Inlet. Shaded boxes show (1) within-site correlations established from supporting lithostratigraphy of samples indicating coseismic submergence and (2) between-site correlations based on sample ages. Samples from other peat-silt couplets are ages from the tops of separate peat or silt-peat horizons, two at Girdwood and three at Ocean View, where diatom data show no evidence for rapid submergence.

To make our estimates more reliable we use results from this year's investigations together with those from our previous investigations (Hamilton, 2003; Shennan *et al.,* 1999; Zong *et al.*, 2003; Shennan *et al.*, 2003). Table1 summarises elevation changes associated with Holocene great earthquakes and other subsidence events.

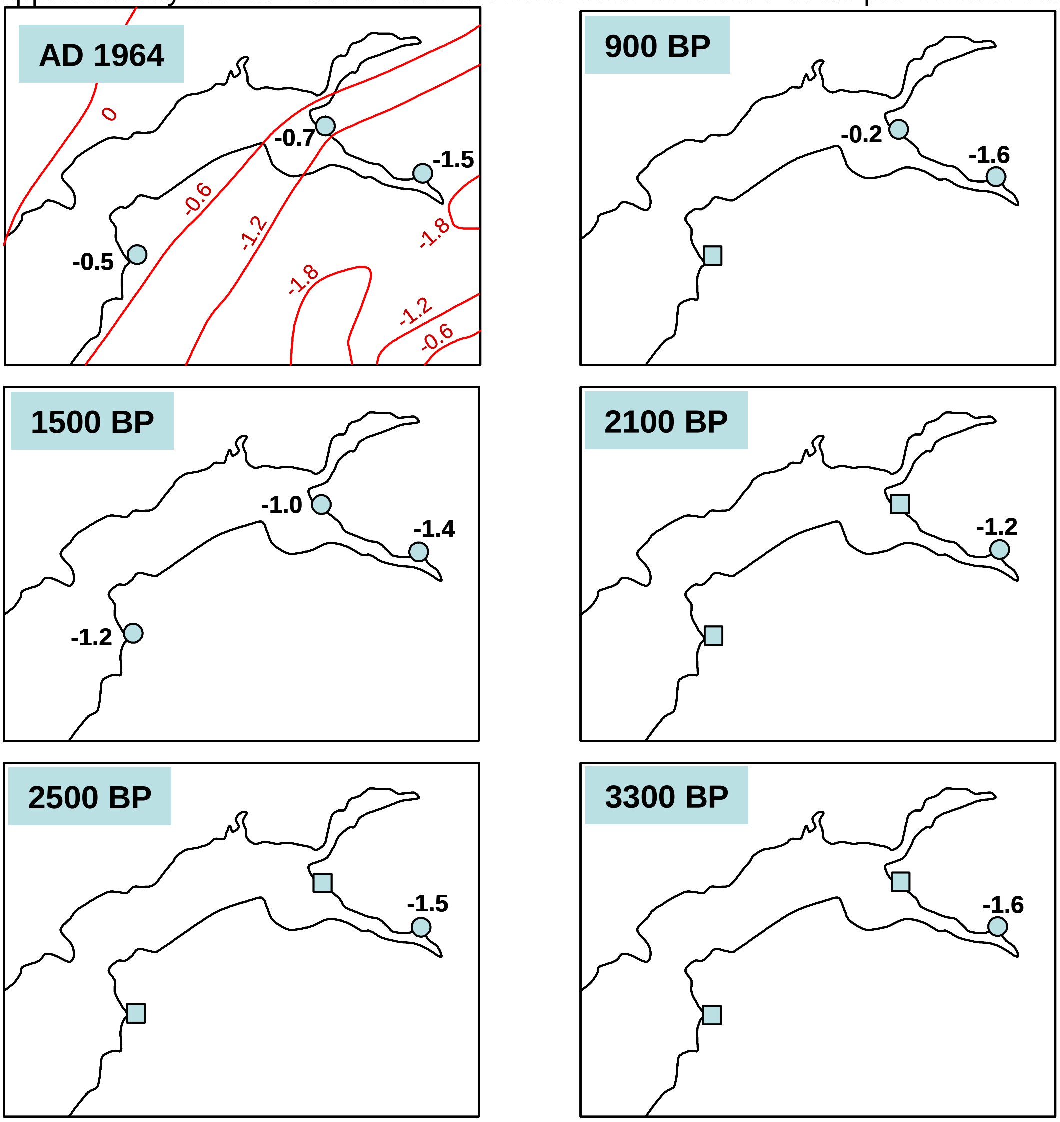
Table 1 *Summary of great earthquakes and other subsidence events*

Site[1]	Peat code[2]	Age[3]	Co-seismic land elevation change (m)	Pre-seismic land elevation change (m)
GW-1	GW-H	AD 1964	-1.51±0.32	-0.24±0.13
GW33	GW-H	AD 1964	-1.48±0.30	-0.16±0.13
GW34	GW-H	AD 1964	-1.34±0.32	-0.33±0.14
GW99	GW-H	AD 1964	-1.00±0.28	-0.30±0.14
KE-3	KE-B	AD 1964	-0.45±0.28	-0.15±0.13
KE-7	KE-B	AD 1964	-0.73±0.24	-0.11±0.12
KE-8	KE-B	AD 1964	-0.30±0.28	-0.15±0.13
KE-13	KE-B	AD 1964	-0.09±0.13	-0.24±0.13
OV-4	OV-E	AD 1964	-0.67±0.43[b]	-0.08±0.23[a,b]
OV-15b	OV-E	AD 1964	-0.71±0.31	-0.10±0.16[a]
GW-1	GW-G	900BP	-1.50±0.34	-0.14±0.14
GW-2	GW-G	900BP	-1.59±0.30	-0.02±0.14
OV-15	OV-D	900BP	-0.23±0.32[b]	too few samples
GW-2	GW-F	1500BP	-1.42±0.29	-0.07±0.13
KE-5	KE-A	1500BP	-1.20±0.27	-0.15±0.13
KE-15	KE-A	1500BP	-1.11±0.27	-0.05±0.15[b]
KE-7	KE-A	1500BP	sediment mixing	sediment mixing
OV-2	OV-C	1500BP	-0.99±0.32[b]	-0.07±0.18[b]
OV-23	OV-C	1500BP	-0.43±0.30	-0.10±0.11[a,b]
OV-23	OV-B[1]	1950BP	None identified	None identified
GW-1	GW-E	2100BP	-1.20±0.34	pollen evidence[c]
GW-2	GW-E	2100BP	-0.79±0.29	too few samples
GW-3	GW-E	2100BP	Non event	Non event
OV-23	OV-B[2]	2200BP	None identified	None identified
OV-23	OV-A	2350BP	None identified	None identified
GW-1	GW-D	2500BP	-1.42±0.34	-0.10±0.18
GW-2	GW-D	2500BP	-1.48±0.42	-0.43±0.46[b]
GW-2	GW-C	2600BP	Non-seismic	Non-seismic
GW-1	GW-B	2800BP	Non-seismic	Non-seismic
GW-2	GW-B	2800BP	Non-seismic	Non-seismic
GW-1	GW-A	3300BP	-1.36±0.30	-0.01±0.16[a]
GW-2	GW-A	3300BP	-1.60±0.32	-0.04±0.18[b]

Notes:
[1] *GW-Girdwood, KE-Kenai, OV-Ocean View*
[2] *Peat layer notations A-H refer to layers at each site but do not indicate chronostratigraphic correlation between Girdwood (GW), Kenai (KE) and Ocean View (OV)*
[3] *Nominal age, used for ease of reference in discussion, see final report for full details*
[a] *no unique diatom assemblage so pre-seismic change may include the effect of mixing from overlying silt.*
[b] *samples have poor modern analogues.* [c] *diatoms absent.*

For the AD 1964 great earthquake, elevation changes at all three locations derived from our bio-stratigraphic analyses show good agreement with observations taken after the earthquake (Figure 3). They agree with the estimates of 1.5 m, for regional subsidence at Girdwood (Plafker *et al.*, 1969), but not any additional subsidence, up to 0.9 m, due to local sediment consolidation recorded for unspecified locations around Girdwood (Plafker *et al.*, 1969). All four Girdwood sites record pre-seismic subsidence in the order of ~0.2 m. ^{137}Cs data show that this commenced in the early 1950s (Shennan *et al.*, 2003) which coincides with observations of increased tidal flooding of the marshes at Girdwood (Karlstrom, 1964).

Estimates for co-seismic subsidence at Ocean View, ~0.7 m, agree with the lower range of measurements around Anchorage 0.7 to 1.5 m (Plafker, 1969) with possible pre-seismic subsidence ~0.1m, but we note the poor modern analogue and the possible effect of sediment mixing (Table 1). Reconstructions from Kenai record ~0.3 to 0.7 m co-seismic subsidence for the three sites on the tidal marsh, diminishing to ~0.1 m, from the pre-1964 acidic bog (KE-13). These are similar to the values suggested by Plafker (1969), approximately 0.5 m. All four sites at Kenai show decimetre-scale pre-seismic subsidence.



○ Stratigraphic evidence for coseismic deformation (m) quantified from diatom transfer function reconstructions

□ No conclusive evidence for coseismic deformation

Contours of deformation (m) from observations after AD 1964 earthquake (after Plafker, 1969)

Fig 3: Co-seismic subsidence during six great earthquakes at three sites around upper Cook Inlet

The penultimate great earthquake, ~900 BP, has a different spatial pattern of subsidence compared to AD 1964. It is not recorded at Kenai and subsidence is less at Ocean View, ~0.2 m. Co-seismic subsidence at Girdwood is similar to AD 1964 but pre-seismic subsidence is less. The ~1500 BP great earthquake shows yet another spatial pattern of subsidence. It is of similar magnitude at Girdwood and Ocean View but larger than AD 1964 at Kenai. Different spatial patterns of co-seismic subsidence for the AD 1964, ~900 BP and ~1500 BP great earthquakes may indicate variations in the location or depth of the rupture zone.

Current evidence from older peat-silt contacts indicate subsidence only at Girdwood, at ~2100 BP, ~2500 BP and ~3300 BP. Our investigations at Kenai record peat accumulation above the limit of tides from ~6500 to 1500 BP with no litho- or bio-stratigraphic evidence of co-seismic subsidence. However, evidence for the ~2100 BP great earthquake at Girdwood (Peat E), where the record of subsidence diminishes from GW-1 which is nearest to the main tidal channel into the Turnagain Arm to marginal sites, GW-2 then GW-3, suggests that other peat-silt couplets at Girdwood and Ocean View currently shown as non-seismic in origin should be studied further. This is a critical next step in the investigation since the ages of these peat layers at Ocean View and Girdwood raise the possibility of great earthquakes less than ~100 years apart.

Pre-seismic relative sea-level rise

Diatom analysis of the peat-silt couplets that record six great earthquakes in the last 3300 years provide evidence of pre-seismic land subsidence (relative sea-level rise) for each earthquake (Table 1). Some of the evidence is more conclusive than others, and we indicate where the signal is possibly enhanced by mixing of sediment and diatoms from the overlying silt into the peat (Hamilton *et al*. 2005) or where the quantitative reconstruction shows a poor modern analogue. Many of the estimates show pre-seismic elevation change smaller than the error term but the fact that it is recorded in the litho- and bio-stratigraphy and the estimates are all negative, indicating land subsidence (relative sea-level rise), rather than a mixture of values either side of zero suggest that this is not a random effect.

NON-TECHNICAL SUMMARY

Field and laboratory analyses of tidal marsh sediment sequences at Ocean View, Girdwood and Kenai provide evidence of six great earthquakes during the last ~3300 years at intervals ranging from ~400 to ~900 years. Different spatial patterns of co-seismic subsidence for the AD 1964, 900 BP and 1500 BP great earthquakes may indicate variations in the location or depth of the rupture zone. Diatom analysis provides quantitative evidence of a period of gradual land subsidence (relative sea-level rise) prior to each great earthquake. Quantifiable pre-seismic land subsidence may be a pre-cursor to a great plate-boundary earthquake.

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